  GLAST LAT SUBSYSTEM TECHNICAL DOCUMENT	Document # <b>LAT-TD-00843-D1</b>	Date Effective Draft 07/17/02
	Prepared by(s) Alex Moiseev	Supersedes None
	Subsystem/Office Anticoincidence Detector Subsystem	
Document Title Design Qualification Tests for ACD TDA and Phototubes		

**Gamma-ray Large Area Space Telescope (GLAST)**  
**Large Area Telescope (LAT)**  
**Design Qualification Tests for ACD TDA and Phototubes**

**DRAFT**

**CHANGE HISTORY LOG**

Revision	Effective Date	Description of Changes

---

## 1. Purpose

This study reports on the performance of ACD tiles of different configurations, including the use of the fiber-to-fiber optical connectors, as well as some qualification tests of phototubes.

## 2. Definitions and Acronyms

ACD	The LAT Anti-Coincidence Detector Subsystem
ADC	Analog-to-Digital Converter
AEM	ACD Electronics Module
ASIC	Application Specific Integrated Circuits
BEA	Base Electronics Assembly
CAL	The LAT Calorimeter Subsystem
DAQ	Data Acquisition
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FM	Flight Module
FMEA	Failure Mode Effect Analysis
FREE	Front End Electronics
GAFE	GLAST ACD Front End – Analog ASIC
GARC	GLAST ACD Readout Controller – Digital ASIC
GEVS	General Environmental Verification Specification
GLAST	Gamma-ray Large Area Space Telescope
HVBS	High Voltage Bias Supply
ICD	Interface Control Document
IDT	Instrument Development Team
I&T	Integration and Test
IRD	Interface Requirements Document
JSC	Johnson Space Center
LAT	Large Area Telescope
MGSE	Mechanical Ground Support Equipment
MLI	Multi-Layer Insulation
MPLS	Multi-purpose Lift Sling
PCB	Printed Circuit Board

PDR	Preliminary Design Review
PMT	Photomultiplier Tube
PVM	Performance Verification Matrix
QA	Quality Assurance
SCL	Spacecraft Command Language
SEL	Single Event Latch-up
SEU	Single Event Upset
SLAC	Stanford Linear Accelerator Center
TACK	Trigger Acknowledge
TDA	Tile Detector Assembly
T&DF	Trigger and Data Flow Subsystem (LAT)
TBD	To Be Determined
TBR	To Be Resolved
TSA	Tile Shell Assembly
TSS	Thermal Synthesizer System
TKR	The LAT Tracker Subsystem
VME	Versa Module Eurocard
WBS	Work Breakdown Structure
WOA	Work Order Authorization

### 3. Applicable Documents

Documents relevant to the ACD Photomultiplier Quality Plan include the following.

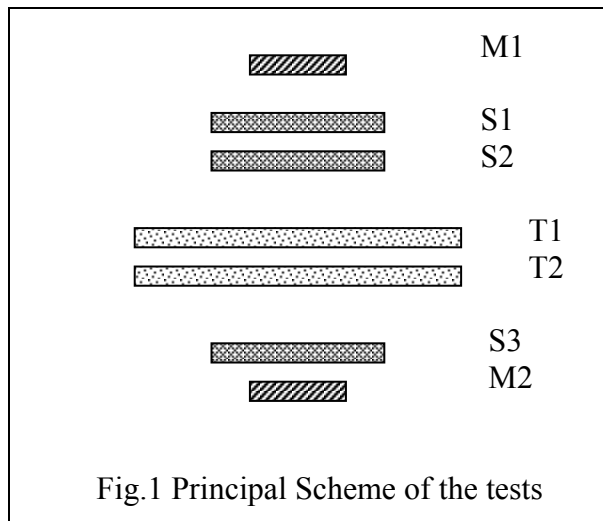
1. LAT-SS-00016, LAT ACD Subsystem Requirements – Level III Specification
2. LAT-SS-00352, LAT ACD Electronics Requirements – Level IV Specification
3. LAT-SS-00437, LAT ACD Mechanical Requirements – Level IV Specification
4. LAT-MD-00039-01, LAT Performance Assurance Implementation Plan (PAIP)
5. LAT-MD-00099-002, LAT EEE Parts Program Control Plan
6. LAT-SS-00107-1, LAT Mechanical Parts Plan
7. LAT-MD-00078-01, LAT System Safety Program Plan (SSPP)
8. ACD-QA-8001, ACD Quality Plan
9. [LAT-TD-00760-D1](#) Selection of ACD Photomultiplier Tube

10. [LAT-DS-00739-1](#) Specifications for ACD Photomultiplier Tubes
11. [LAT-TD-00438-D2](#) LAT ACD Light Collection/Optical Performance Tests
12. [LAT-TD-00720-D1](#) ACD Phototube Helium Sensitivity
13. [LAT-DS-00740-1](#) Temperature Characteristics of ACD Photomultiplier Tubes
14. Response to RFQ 5-09742, Hamamatsu Photomultiplier Tube Proposal

#### 4. The experimental approach.

Tile performance is measured by collecting the pulse-heights of signals created by cosmic muons in the tile. For the tile efficiency measurement, the muon selection scheme has to be reliable, with the level of false triggers less than 1:10,000. This was achieved by triggering the data acquisition by the coincidence of two triggering scintillators (M1 and

M2), and selecting the events for the efficiency analysis by applying tight muon-like pulse-height requirements to the signals from S1, S2, and S3. Signals from tiles T1 and T2 are used for the efficiency measurements.

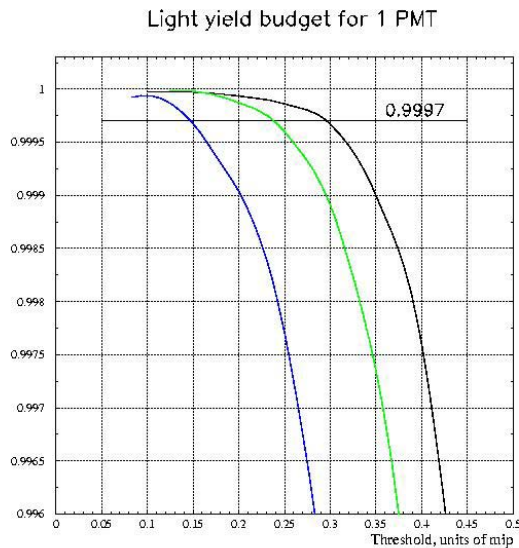


#### 5. Earlier Tests, for Reference (from LAT-TD-00438-D2)

The absolute efficiency of a TDA (Tile detector assembly) has been measured, and the corresponding light yield estimated. The measurements have been performed with relatively short fibers (only WSF), which collect the light from the tile and deliver it to the PMT. In the real design there will be fiber bundles up to 1.5 meters long to deliver the light from the most distant tiles (in the middle of the top ACD surface) to the PMT location. Two cases are considered: (1) the resulting efficiency if no clear fibers are used and light is delivered to a PMT by only WSF (1.5 meters long, 40% light loss assuming the published absorption length); and (2) the use of fiber-to-fiber connectors and clear fibers to deliver the light to PMT. (Clear fibers are assumed to be much more transparent, with light loss assumed to be ~15% due to losses in the connector between

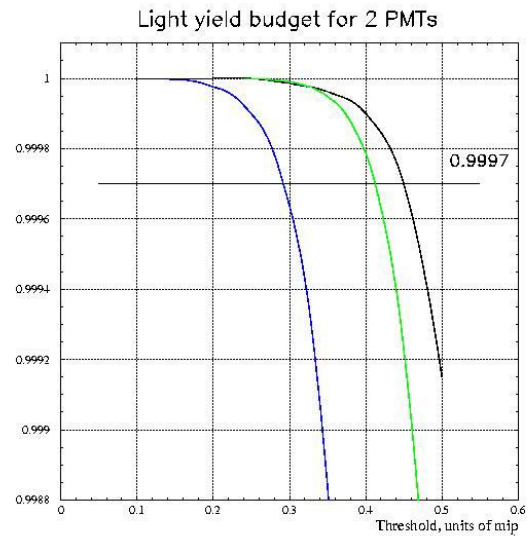
the WSF and clear fibers. NOTE: This assumption later proved to be incorrect; at least initially, losses in the clear fibers seem to be nearly as great as those in WSF.)

These tests were done using a Goddard-made tile and commercial Hamamatsu R647 phototubes. The results, shown in Fig. 2 and Fig. 3, show the measured efficiencies for one and two phototubes on a single tile, along with the calculated light losses for longer fibers or connectors to clear fibers. Light loss in the clear fibers was assumed to be nil (but see the note just above).



**Fig.2. Light budget for 1 PMT.**

Black line – measured efficiency (corresponds to 19 p.e.)  
 Green line – efficiency assuming 15% light loss (16 p.e.)  
 in the fiber connector and clear fibers  
 Blue line – efficiency assuming 40% light loss (12 p.e.) in  
 1.5 meters WSF

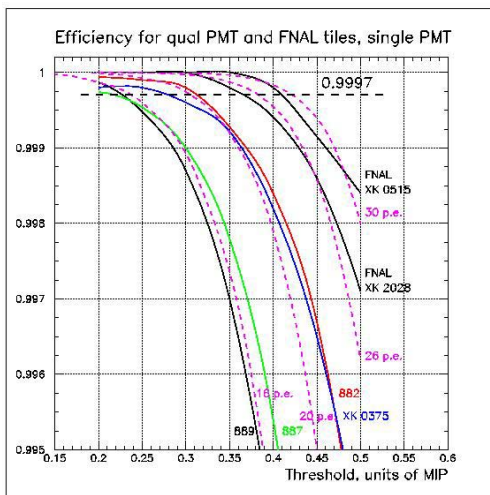


**Fig.3. Light budget for 2 PMTs.**

Black line – measured efficiency  
 Green line – efficiency assuming 15% light loss  
 Blue line – efficiency assuming 40% light loss

## 6. Test of FNAL first flight-prototype tile

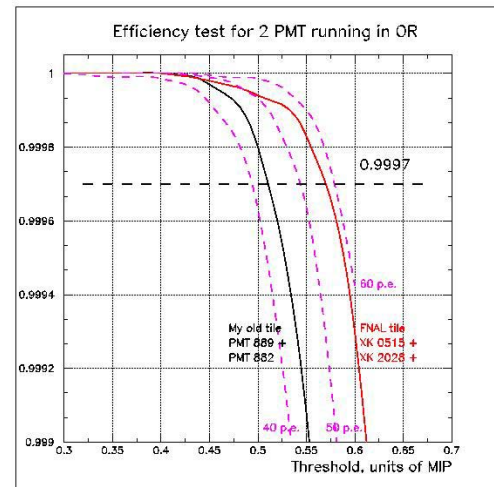
The task was to see the performance of the first FNAL tile, compared to the tiles made at Goddard. This tile actually has all our potential improvements, and is expected to have about 30% light yield increase compared with my flight prototypes (due to aluminization of the fiber ends). The results for one of two PMTs (from one tile) running are shown in fig. 4, and for both PMT running in “OR” in fig. 5. The black lines labeled by “FNAL XK 0515” and “FNAL XK 2028” in Fig. 4 correspond to two bundles from the first FNAL tile, viewed by R647 commercial PMT. In Fig. 5, the red line corresponds to an OR of the signals from these two tubes. The pink dashed lines is a fitted efficiency, from a Poisson distribution assuming some number of photoelectrons (p.e). The superior performance of the new tile made at Fermilab is demonstrated by comparison to the black lines in Fig. 2 and 3 above, made with the GSFC tile. These measurements were all made close to the tile, with no long fibers.



**Fig.4. Light budget for 1 PMT.**

FNAL lines – measured efficiency using commercial phototubes on the FNAL tile, with corresponding p.e. calculations.

Other lines – measured efficiency using various phototubes on the GSFC tile, with corresponding p.e. calculations. These curves compare to the black line in Fig. 2.



**Fig.5. Light budget for 2 PMTs.**

FNAL line – measured efficiency using 2 commercial phototubes on the FNAL tile, with corresponding p.e. calculations.

Black line – measured efficiency using 2 phototubes on the GSFC tile, with corresponding p.e. calculations. This curve compares to the black line in Fig. 3.

## 7. Test of the First Qualification PMTs.

Figures 4 and 5 also show results for the first qualification-type R4443 phototubes from Hamamatsu. In Fig. 4, the lines labeled by 887 (green), 889 (black), and 882 (red), show single-phototube efficiency measurements using the GSFC tile and the R4443 tubes with these serial numbers. These curves can be compared to the black curve in Fig. 2, made using a commercial tube. As can be seen, the 889 and 887 tubes do not perform as well as the commercial tube. In consultation with Hamamatsu, we learned that these tubes have a lower quantum efficiency than the 882 tube that does produce results as good as the commercial tube. For this reason, we have added to our phototube specification the requirement that the quantum efficiency at 490 nm (the waveshifting fiber peak output) be no less than 15.5%. Using this criterion, tubes 889 and 887 were rejected, while tube 882 was accepted. The OR of tubes 882 and 887 attached to the GSFC tile is shown as the black curve in Fig. 5. Despite the lower performance of the 887 tube, the combination of the two produces an efficiency that is slightly higher than that measured with the commercial tubes (the black curve in Fig. 3). These tests confirm that the R4443 tubes meet the ACD efficiency requirements.

## 8. Tests of different tiles and fiber coupling to phototubes.

In these tests the position of the MIP peak position in the pulse-height histogram was determined, using the same scheme of the measurements as described above, for a variety of tiles and light collection methods. The measurement results are summarized in Table 1. Three important conclusions can be drawn from this table:

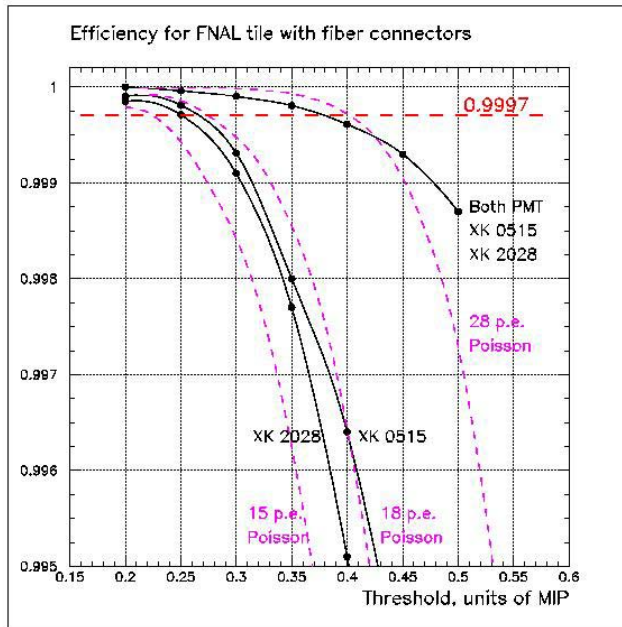
- The bent tile performs as well as the flat tile, even through the bent region. This test confirms that the bending does not cause an appreciable loss of light.
- The light loss through the optical fiber-to-fiber connector and a 1.2 m long clear fiber bundle is substantial. It was very discouraging to see such a big light loss in case of green fiber coupling to the clear fibers (~40% light yield reduction). This was true whether the polishing of the fiber ends was done by hand or with a diamond mill. The loss is far greater than that estimated in section 2 above, which assumed the principal loss to be 15% loss in the optical connector.
- Thermal bonding of the waveshifting fibers to clear fibers produces no better results than connecting the fibers through the optical connector. The problem seems to be independent of the coupling method.



**Table 1. Pulse Heights (channels) for various combinations of tile, fibers, and PMTs**

MIP peak position	FNAL first tile (for this tile the efficiency given above was measured)	FNAL bent tile, center of the tile	FNAL bent tile, area of bending	FNAL tile with fiber-to-fiber connector to clear fibers, hand fiber ends polishing	FNAL tile with fiber-to-fiber connector to clear fibers, diamond milled fiber ends	FNAL tile with thermally coupled clear fibers
PMT XK 0515	469.3 (measured 3 times)	486.9	497.5	243.5	F 254.5	221.1
PMT XK 2028	527.3 (measured 3 times)	542.8	552.8	267.7	281.4 336.0 331.0 571.0	232.8 309.0 328.0 496.9 640.0

A long-term (4 days) efficiency measurement was performed on the tile with the optical connector and clear fiber bundle to be sure that the efficiency degradation is consistent with the MIP peak shift. This test represents a complete end-to-end test of a flight-like Tile Detector Assembly: scintillator, waveshifting fiber, optical connector, clear fiber, photomultiplier tube. The results are shown in fig. 6. For the individual tubes, the measured efficiency at the nominal threshold of 0.3 MIP is above 0.9990 but below the ACD efficiency requirement of 0.9997. For the combination of the two tubes, the efficiency meets the ACD requirement with some margin. From a comparison with Figures 2 and 3 it can be seen that the loss of light in the connector and clear fibers offsets the gains made with the improved Fermilab tile.



**Fig. 6.** Efficiency measurement for a complete flight-like assembly. The curves to the left are for individual phototubes connected to one flight-type scintillator tile through waveshifting fibers, an optical connector, and a clear fiber bundle. The curve to the right is the OR of the signals from the two tubes.

In Table 1, comparison should be made between lines measured with first FNAL tile with no optical connectors, shown on figures 4 and 5 (“FNAL XK 0515” and “FNAL 2028”) and lines labeled “XK 0515” and “XK 2028” on fig. 6 measured for the tile with optical connector and clear fibers. Comparison of estimated light yield (26-30 p.e. for the former assembly, and 15-18 p.e. for the latter one) demonstrates a good agreement with muon peak shift. This comparison shows the validity of measuring the muon peak as a tracer of performance rather than always requiring a complete efficiency measurement, which typically requires much longer observation.

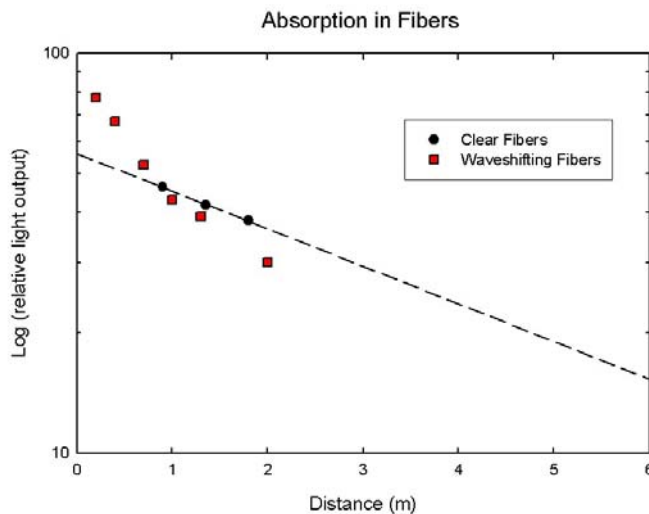
## 9. Tests of absorption in clear fibers.

In attempting to trace the loss of light in the full optical assembly, we measured the peak position of the MIP peak in scintillators using varying lengths of clear fiber. The results are summarized in Table 2. It seems obvious from these measurements that the clear fibers we are using (Bicron, nominally multiclاد 1.2mm, but Bicron now claims they have never made such fibers. They may be single-clad instead of multiclاد.), have a significant absorption, probably more than implied by the nominal 12 m absorption length quoted by Bicron. It appears that at least as much light is lost in the 1.2 m fibers as in the optical connector.

**Table 2. Pulse Heights (channels) with different length of clear fibers, compared with clear fibers and connector removed:**

	FNAL tile with connector	FNAL tile with thermal splices
PMT XK 0515		
FNAL polishing 1.2m clear fibers	304	278
B.D. polishing, 1.2m clear fibers	296	
B.D. polishing, 20cm clear fibers	-	428
B.D. polishing, no connector	530	559
PMT XK 2028		
FNAL polishing, 1.2m clear fibers	336	309
B.D. polishing, 1.2m clear fibers	331	328
B.D. polishing, 20cm clear fibers		497
B.D. polishing, no connector	571	640

A 1.8 m sample of the clear fiber was sent to Fermilab for an independent measurement of the absorption. The results are shown in Fig. 7



**Fig. 7** Light absorption in clear and waveshifting fibers (relative). The three points for the clear fibers suggest an absorption length ( $1/e$  length) of about 5 m. An 18% light loss is seen between 0.9 m length fibers and 1.8 m length fibers.

Although the absorption is significantly larger in the waveshifting fibers, the additional loss in the optical connector implies that a careful tradeoff must be done between longer waveshifting fibers and an optical connector/clear fiber approach. A preliminary analysis suggests that the break-even point comes at about 0.7 m. Any tile closer than this to its phototubes would benefit from using waveshifting fibers only.

A concern is that the absorption in the clear fibers is much larger than advertised by Bicon. There is some possibility that the clear fibers were single clad rather than multi-clad (Bicon says they have no record of selling us multi-clad fibers). Additional clear fibers have been ordered, explicitly multicladd. Further testing is needed before the design is finalized.

## 10. Conclusion

Figure 6 gives us an understanding of the real light budget. It appears that we lost all our gains for last 1.5 years (we are back to 15-18 p.e.), but we are still meeting our requirements (but with little margin). If we look at the fig.7, where the light attenuation for green fibers (WSF) is shown (preliminary measurements), we see that only for the central top tiles will the light loss due to the connector be comparable to that of the attenuation in the green fibers. For all other tiles, the use of only green fibers looks preferable; however, the fabrication, shipping and assembly will be a nightmare. The light loss in the clear fibers should be studied, as well as the reason our connectors give such a big loss (FNAL data give 12-15% loss in similar connectors).